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ANALYSIS OF FLIGHT SERVICE STATION CONSOLIDATION. PHASE III: INDIANAPOLIS, FORT WAYNE, AND TERRE HAUTE FLIGHT SERVICE STATIONS.

10 Lee/Paul

Ephraim/Shochet

James D./Talotta

FEDERAL AVIATION ADMINISTRATION TECHNICAL CENTER

Atlantic City, N. J. 08405

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16. Abstract

A study was made to evaluate the effect of consolidating the Indianapolis, Terre Haute, and Fort Wayne Flight Service Stations (FSS) into one facility. This report documents the estimated effect of consolidation on specialist productivity, distribution of workload, staffing requirements, and service to the user. Queuing theory was used to determine what one might expect in the way of number of delays, amount of delay, number waiting, etc. In addition, analyses were made to estimate the effect of decreasing the number of specialists while assuming the same demand and increasing the demand while assuming the same number of specialists. The data collected clearly supports the expected value of consolidation and must be regarded as an encouraging indication that the present system can be made to operate more efficiently and provide better service to the users. Providing the users access to a larger number of specialists than are normally available at the nearest FSS should permit better service with fewer delays and a more equitable distribution of the workload, other things being equal.

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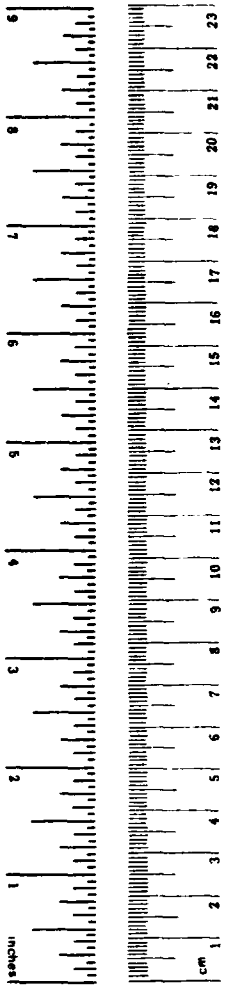
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.036	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

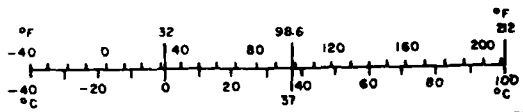


TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

PURPOSE.

The purpose of this report is to document the results of a study designed to estimate the effect of flight service station (FSS) consolidation on specialist productivity, distribution of workload, staffing requirements, and service to the user.

BACKGROUND.

Air Traffic Service (AAT-1) and Air Traffic and Airway Facilities' Program Management Staff (ATF-4) requested a study to estimate the potential benefits of consolidating separate FSS's. The study was divided into three phases. Phase I provided an analysis of FSS consolidation and sectorization for Charlottesville, Richmond, and Leesburg, Virginia (reference 1). Richmond FSS and Charlottesville FSS were operationally consolidated into Washington FSS in April 1977 and July 1977, respectively, and a before and after comparison was made on this consolidation (reference 2). Phase II provided an analysis of FSS consolidation and sectorization for Las Vegas, Tonopah, and Ely, Nevada, and Needles, California (reference 3). Phase III estimated the effect of consolidating the Indianapolis, Terre Haute, and Fort Wayne, Indiana FSS's into one facility. This report documents the results of phase III.

METHODOLOGY

PROCEDURE FOR DATA COLLECTION.

The facilities studied were Indianapolis (IND), Fort Wayne (FWA), and Terre Haute (HUF) FSS's. Data collection in the sample was conducted at each of the three separate facilities over a 9-day interval from August 24, 1977, to September 1, 1977. A total of seven data collectors (six air traffic control specialists and one research psychologist) from the Federal Aviation Administration (FAA) Technical Center were divided into teams and assigned to each of the facilities. Data were simultaneously collected by each of the teams on a predefined schedule. Six hours of activity were studied over different 8-hour intervals on each of 6 different days for a total of 48 hours of work activity. During the 8 days, all 24 hours of the day were monitored (table 1).

This presented an around-the-clock sample of facility workload. The study focused on the primary operational preflight duties common to FSS's. Activity relating to the in-flight and flight data positions was recorded manually on a moving paper chart (kymograph) using descriptive work activity codes. In this same manner, in-person preflight transactions were recorded and included in the sample. Telephone activity for the preflight position was recorded on a telephone traffic computer. This traffic computer made a permanent recording of all preflight telephone briefing activity on an individual call basis and was then manually reduced and compiled for analysis. Also available for use in the analysis were historical activity records including flight plan forms and pilot briefing logs obtained from each facility after the normal 15-day retention period.

TABLE 1. DATA COLLECTION SCHEDULE

Hour	Date								Total By Hour
	8/24	8/25	8/26	8/27	8/28	8/30	8/31	9/1	
00								X	1
01								X	1
02							X		1
03							X	X	2
04						X		X	2
05						X	X		2
06				X			X	X	3
07				X		X		X	3
08					X	X	X		3
09				X	X		X		3
10			X	X		X			3
11			X		X	X			3
12				X	X				2
13			X	X					2
14		X	X		X				3
15		X			X				2
16	X		X						2
17	X	X	X						3
18		X							1
19	X								1
20	X	X							2
21		X							1
22	X								1
23	X								1
Total	6	6	6	6	6	6	6	6	48

It was expected that the most significant impact of consolidation would be demonstrated at the operational preflight position, since the majority of the accountable workload in the present FSS system consists of preflight calls to obtain a weather briefing and/or to file a flight plan. Therefore, we have limited this analysis to the preflight briefing position.

In order to define precisely the number of specialists available to provide preflight service, the data collection personnel made an observation of a facility on cue at 5-minute intervals. A specialist was considered available for preflight if the following criteria were met:

1. The specialist was assigned preflight as a primary or collateral duty.

2. The specialist was physically at the position.

3. The specialist was not engaged in another type of duty such as emergency service, in-flight, or flight data.

This sampling method provided an account of actual specialist availability, considering the variety of tasks a specialist may perform.

The prevailing weather during the sample periods was noted on an hourly basis and classified as instrument flight rules (IFR), ceiling 500 feet to less than 1,000 feet and/or visibility 3 to 5 miles inclusive; marginal visual flight rules (MVFR), ceiling 1,000 to 3,000 feet and/or visibility 3 to 5 miles inclusive; and visual flight rules (VFR), ceiling greater than 3,000 feet and visibility greater than 5 miles, includes sky clear.

The specific data items measured in this study were as follows:

1. The number of specialists assigned preflight briefing duties.

2. The number of specialists available for preflight briefing duties.

3. The total number of transactions or calls processed.

4. The number of lost calls (those calls abandoned by the caller prior to being connected).

5. The duration of call waiting time (time interval between first ring and acceptance of the call).

6. The duration of each transaction or preflight call.

The above data were collected and summarized for each of the 48 1-hour data collection periods at each of the three FSS's in this study. This information is shown on the Queuing Model Application Forms (appendix B) which give the location, date, time, and prevailing weather--VFR, MVFR, IFR--and provide an analysis of the data collected. Items A to G of the form are:

A--Number of servers (mean number of specialists available for preflight transactions).

B--Number of transactions (number of preflight transactions that occurred).

C--Average serving time (average number of minutes actually spent on the transaction).

D--Observed waiting time (average number of seconds caller was on hold before talking to a specialist).

E--Number of calls delayed (number of callers on hold more than 15 seconds before talking to a preflight specialist).

F--Average time of delay (mean number of seconds of delay for calls that were put on hold).

G--Number of calls lost (caller hung up before talking to a specialist).

RESULTS

OBSERVATIONS OF DEMAND AND SERVICE TIMES.

One of the more remarkable aspects of the data is its enormous variability. The number of transactions occurring in a single facility in a single hour ranged from a maximum of 61 (IND on 8/30/77 at 1000) to several lows of 0 (HUF on 8/31/77 at 0200, 9/1/77 at 0300; and FWA on 8/31/77 at 0200 and 0300, and 9/1/77 at 0100). The number of specialists available for preflight transactions ranged from a high of 4 at IND to a low of 0.5 at FWA.

Another comparison is the number of transactions per hour for the different FSS's. Table 2 shows this data averaged over the 48 1-hour collection periods. We find that IND averages three times the traffic of HUF and FWA. Interestingly, when the average number of transactions is divided by the average number of specialists available, IND averages twice the average number of briefings per specialist per hour. This may reflect the greater flexibility of a larger facility to schedule its personnel to meet the large daily fluctuations in demand. The latter is supported by the higher correlation coefficient, 0.75, between the number of preflight specialists available and the number of transactions for IND than for the others.

TABLE 2. NUMBER OF TRANSACTIONS AND SPECIALISTS PER HOUR, BY FACILITY AND COMBINED

	IND	HUF	FWA	TOTAL
Average Transactions Per Hour	27.63	9.17	9.58	15.29
Standard Deviation of Transactions Per Hour	16.04	6.26	5.62	13.39
Average Number of Specialists Per Hour	2.75	1.69	1.98	2.13
Standard Deviation of Specialist Per Hour	1.01	.65	.77	.93
Average Number Transactions Per Specialist	10.1:1	5.4:1	4.8:1	7.18:1
Correlation Between Number of Transactions and Number of Specialists	.75	.54	.64	.74

Hourly fluctuations reflect a daily cycle of variation in demand. Call rates build up rapidly from 0400 to 0800, then gradually taper off by midnight (figure 1). One source of variability in the data seems related to the weather conditions. Previous reports indicated that there is a relationship between weather conditions and the time required to give a preflight weather briefing. The data reported here are somewhat more definitive since they were collected over a wide variety of weather conditions (table 3). It seemed appropriate for this analysis to look not only at the weather conditions reported during the hour of data collection, but also for the entire 7-hour data collection "day." That is, a separate analysis was made for VFR hours that occurred during all-VFR "days" and VFR hours that occurred during "days" that also had IFR and MVFR hours. We found that the mean time per briefing, in minutes, is 2.14 for briefings during all-VFR days, 2.49 for briefings during MVFR conditions, and 2.55 for briefings during IFR conditions.

Weather briefings made during hours characterized as VFR but occurring on "days" that had IFR and/or MVFR weather took an average of 2.55 minutes. An analysis of variance of these briefing times (table 4) shows that the weather conditions are a statistically significant factor with respect to briefing times and that briefings given under all-VFR conditions take significantly less time than briefings given during MVFR conditions, IFR conditions, and VFR conditions on other than all-VFR days.

The major concern of this report has to do with the potential savings that might be expected from consolidation. The model for predicting these savings is based on queuing theory and might well be reviewed at this point before it is applied to the data.

THE QUEUING MODEL.

A definitive reference on the topic is James Martin's "System Analysis for Data Transmission" (reference 4). Martin points out that in order to apply the queuing model sensibly, one must make a number of assumptions about the system to which it is being applied, in this case, the preflight function of the FSS. The most general requirement, and the easiest to meet with respect to telephoned requests for preflight briefings, is the random nature or statistical independence of demand. Where there are multiserver queues, and especially in considering consolidation, there are additional requirements. We must assume that all servers are able to adequately perform the required function. This means not only individual competence but also equal access to the required information. We must also assume that when people are waiting for service there is a queue or a line on which they may be held rather than receiving a busy signal. We will also assume that people are served in the order they call and that the caller at the front of the queue is served by the next available server or specialist. In applying the multiserver model, quantitative predictions require additional assumptions:

1. The arrival pattern of incoming calls follows a Poisson distribution.

2. The distribution of times required to perform the service is exponential.

3. All servers are equally loaded.

4. All servers have the same mean service time.

5. No one who calls in and is put on hold will leave the queue; i.e., hang up.

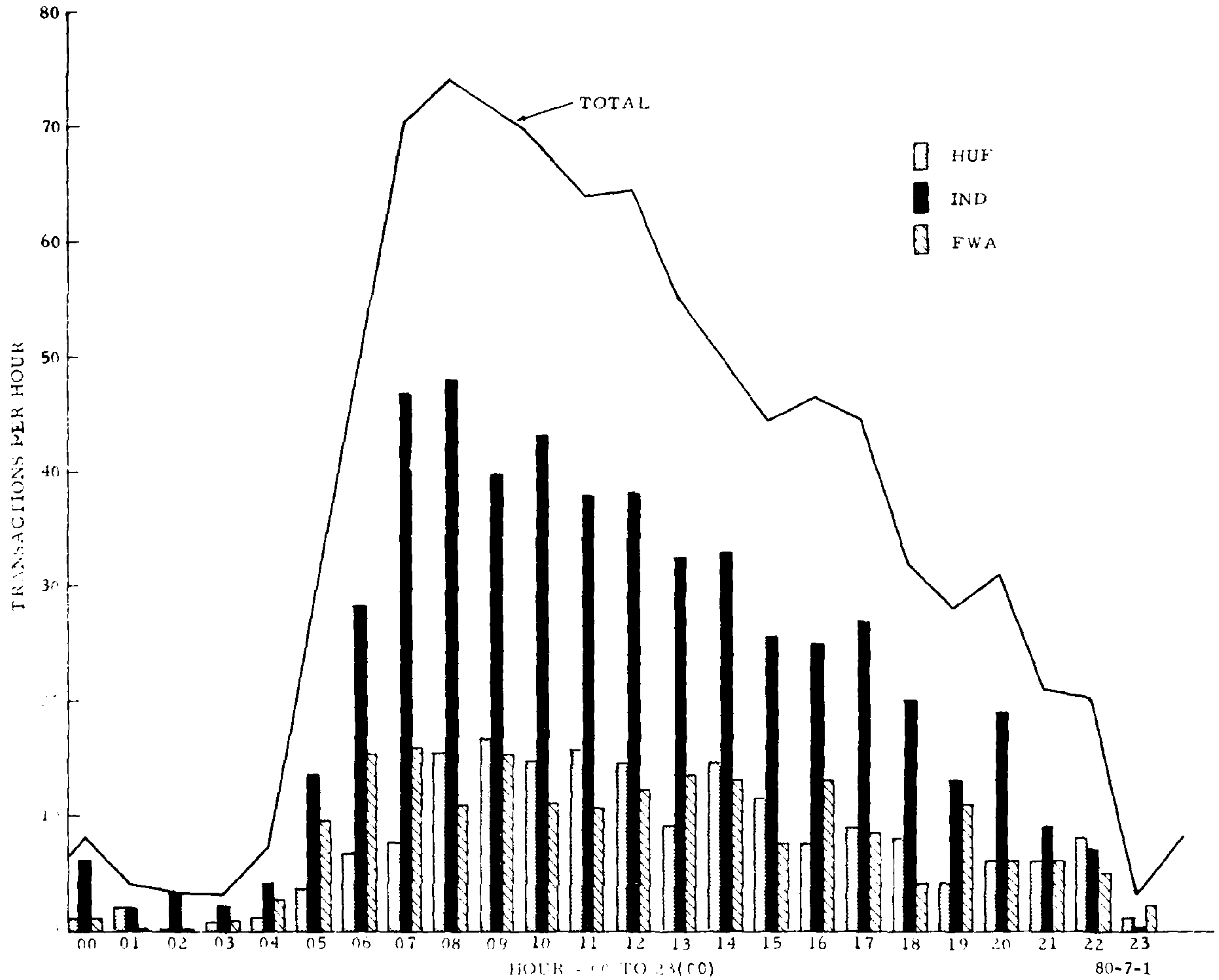


FIGURE 1. FLIGHT SERVICE STATION'S HOURLY NUMBER OF CALLS

TABLE 3. PREFLIGHT TRANSACTION TIME AND WEATHER

	All VFR	VFR, Mixed	MVFR	IFR	Total
Number of Transactions (N)	778	265	677	451	2171
Mean Service Time (Minutes) Et_s	2.14	2.55	2.49	2.55	2.38
Standard Deviation of Service Time $\sigma(t_s)$	2.41	2.29	2.05	2.56	2.33

TABLE 4. TRANSACTION TIME ANALYSIS OF VARIANCE

Source of Variance	df	SS	MS	F
Total	2170	11,801.3		
Between	3	72.5	24.17	4.47*
Within	2167	11,728.8	5.41	*significant at the 0.025 level

Legend:

df--Degrees of Freedom
SS--Sum Squares
MS--Mean Square
F--Ratio

If these assumptions can be met, certain conclusions follow automatically when more than a single server is needed. People will be better served if they have free access to all available servers, as opposed to limited groups of customers being assigned to single servers and waiting for those servers to be free; the more one combines service areas and servers, the better the service. The strength of this model is that it isolates certain parameters of the overall system configuration and permits them to be explored quantitatively; its weakness is that it ignores other significant factors. Keeping that in mind, let us look more closely at the model.

An important parameter in describing the demand on the system during any given interval is called utilization. In Martin's book, utilization is symbolized by ρ (rho) in formulas. This report will use the symbol r. It is the ratio of the load on a facility to the maximum load that can be handled, or the time the facility is occupied to the time available. When the interval is 1 hour and the service time is expressed in minutes, a 1-hour period with 20 trans actions, E(n), having an average duration of 2.5 minutes, $E(t_s)$, would have a utilization of $r = E(n) \times E(t_s)/60$, or $20 \times 2.5/60 = 0.8333$, if only one server is available. When more than one server is present, $r = E(n) \times E(t_s)/(60 \times M)$, where M is the number of servers. In the previous example, with two servers, $r = 20 \times 2.5/(60 \times 2) = 0.41667$.

The next important statistic in the queuing model is B, the probability that all servers are busy in a multiserver queuing system. It is the probability that a user will have to stand in the queue or be put on hold before getting service. B, which is equal to r when M = 1, is used to compute a number of other system parameters and its formula, which is complex, is included in the appendix. $B \times r/(1-r) = E(w)$, the average number of people waiting for service. The expected length of the queue, which includes those waiting plus those being served, is $E(q) = E(w) + M \times r$. The average amount of time spent waiting for service is $E(t_w) = B \times E(t_s)/M \times (1-r)$, while the average time waiting, considering only those who do wait, is $E(t_d) = E(t_w)/B$.

Applying the analysis to some data will demonstrate the meaning of these parameters in a tangible way. In table 5, Hypothetical Data, there is some data concerning a single hour's activities in an FSS. Items A through G represent observed data; items H through O are parameters computed from them. For the hour represented under column I, actual measurement might show there were 5 specialists (A) who handled 50 preflight briefings (B) which took an average of 2 minutes (C) each to complete. During this hour, the 50 people given briefings waited an average of 20 seconds (D) each for their briefing to begin, but only 15 (E) actually waited and their average wait was 67 seconds (F).

Applying the queuing theory to the above "observed" data produced the following statistics:

H--Probability of waiting (B) = 0.030.

I--Utilization (r) = 50 x 2.00/(5.0 x 60) = 0.333.

J--Intensity (M x r) = 1.667.

K--Average number waiting E(w) = 0.015.

TABLE 5. HYPOTHETICAL DATA

QUEUING MODEL APPLICATION FORM

LOCATION:
DATE:
WX:

		I	II	III	IV
A.	Number of servers M	5	5	4	2
B.	Number of transactions N	50	50	50	50
C.	Average serving time* $E(t_s)$	2	3	2	2
D.	Observed waiting time (sec)	20	20	20	20
E.	Number of calls delayed E(w)	15	15	15	15
F.	Average time of delay (sec)	67	67	67	67
G.	Number of calls lost	3	3	3	3
H.	Probability of waiting B (E)**	.030	.130	.103	.758
I.	Utilization r (05)**	.333	.500	.417	.833
J.	Intensity M x r (06)**	1.667	2.500	1.667	1.667
K.	Average number waiting E(w) (A')*	.015	.130	.073	3.788
L.	Average number in queue E(q) (B')**	1.682	2.630	1.740	5.455
M.	Average time* waiting $E(t_w)$ (C')**	.018	.156	.088	4.546
N.	Average time* in queue $E(t_q)$ (C'+02)**	2.018	3.156	2.088	6.546
O.	Average time* for those $E(t_d)$ delayed (C'/10)**	.600	1.2	.857	6.000

*Minutes
**Refer to SR-52 program (appendix A).

L--Average number in queue $E(q) = 1.682$ (number waiting, $E(w)$, plus number of briefers (M), times utilization.

M--Average time waiting $E(t_w) = 0.018$ minutes.

N--Average time in queue $E(t_q) = 2.018$ minutes (time waiting plus time being briefed $E(t_s)$.

O--Average waiting time for those required to wait $E(t_d) = 0.600$ minutes $(E(t_w)/B)$.

In column II of table 5 we have recomputed the statistics assuming only that the briefing time increased from 2 to 3 minutes, a 50 percent increase. Note that the probability of waiting, B, has increased four-fold while the number waiting, $E(w)$, and the time waiting, $E(t_w)$, have increased by a factor of eight. The average waiting time for those delayed, $E(t_d)$, has doubled. Still, the situation is only slightly worse.

In column III we have gone back to the original briefing time, but decreased the number of briefers from five to four. There is now one chance in ten of having to wait, and that wait would average 1 minute.

In column IV, the number of briefers is reduced to two, and the situation has noticeably worsened. With a utilization of greater than 0.8 there is a 75 percent chance of waiting and the average wait has now increased to 6 minutes.

The preceding analysis will now be applied to some of the data actually collected at Indianapolis, Fort Wayne, and Terra Haute.

ANALYSIS OF THE DATA.

The busiest single hour was 0700 on 8/30/77. The data for this period is shown in the Queuing Model Application Form for each of the facilities in appendix B, pages B-1 to B-3. In the first column for each of the facilities, there are two figures for number of servers. The first is an integer that is used to compute the queuing parameters, the second is in brackets and is the average number of specialists actually available during the hour. There is also a form with the hypothetical location "consolidated," appendix B-4. Items A to G are the total or average values of the three facilities as appropriate; i.e., the sum of the servers and number of transactions, but the average of the serving times and the average of the delay times. It is an attempt to portray the events as if they had all taken place in a single location.

The next stage in the analysis is a Data Summary, appendix B-5, which simply combines a few key statistics on the separate application forms. These are, for several values of number of specialists, the model's prediction of the percent of callers who will have to wait for service, the average time they will wait, and the percent of utilization. This provides the information on a single page that permits one to compare the effectiveness of different numbers of specialists at separate and combined locations.

Finally, the Summary Analysis, table 6, shows the number and length of delays as a function of the number of specialists used and the manner of their allocation. Note that with separate facilities, the allocation of a given number of specialists

TABLE 6. SUMMARY ANALYSIS FOR 8/30/77, 0700 (BUSIEST HOUR)

Average number of specialists available

IND - 3.67	HUF - 1.42	FWA - 2.5	Total - 7.59

Number of transactions

IND - 57	HUF - 15	FWA - 15	Total - 87

Average time per briefing (minutes)

IND - 2.46	HUF - 2.28	FWA - 3.57	Total - 2.62

7 Specialists	IND 5	5.9 delays averaging 0.92 minutes	
	HUF 1	8.6 delays averaging 5.30 minutes	
	FWA 1	13.4 delays averaging 33.2 minutes	
	Total 7	27.9 delays averaging 17.8 minutes	
	IND 3	35.0 delays averaging 3.71 minutes	
	HUF 2	1.9 delays averaging 1.59 minutes	
	FWA 2	4.1 delays averaging 3.22 minutes	
	Total 7	41.0 delays averaging 3.56 minutes	
	Consolidated 7	9.5 delays averaging 0.82 minutes	
6 Specialists	IND 3	35.0 delays averaging 3.71 minutes	
	HUF 1	8.6 delays averaging 5.30 minutes	
	FWA 2	4.1 delays averaging 3.22 minutes	
	Total 6	47.7 delays averaging 3.96 minutes	
	Consolidated 6	20.7 delays averaging 1.19 minutes	
5 Specialists			
	Consolidated 5	41.7 delays averaging 2.18 minutes	
4 Specialists			
	Consolidated 4	77.5 delays averaging 13.1 minutes	

has a great effect on the number and length of delays. Also, that five specialists in a hypothetical consolidated facility offer fewer and shorter delays than any likely combination of seven specialists at separate facilities.

Identical analyses have been performed on several additional representative periods of high, medium, and low activity to demonstrate that the single 1-hour period was not atypical. The data for 8/26/77 at 1000 (table 7) show that there is a 4 1/2-minute difference in average waiting time, depending on how three specialists are allocated between HUF and FWA. Further, the data show that five specialists working in the consolidated mode provide better service than any reasonable combination of seven specialist working at three separate facilities.

The data from 8/25/77, 1400, table 8, show that four consolidated specialists could be expected to do better than seven at separate facilities and that even three appear to be able to handle the work without unreasonable delay; i.e., a 75-second delay for those having to wait.

During the next hour, 8/25/77, 1500, table 9, three consolidated specialists are predicted to handle the load of seven with less than a 20-second increase.

Tables 10 and 11 for 8/30/77, 0400, and 9/1/77, 0000, respectively, demonstrate some of the risks as well as the advantages of following the queuing model literally. Both were selected as examples of very low activity periods that presently require a minimum of three specialists for minimum manning. The table 11 data show that one specialist can handle the eight briefings with an average wait of 2.22 minutes, 80 seconds less than the three separated specialists. On the other hand, table 10, where nine briefings were performed, shows that with one consolidated position, delays increase from 10 minutes with three specialists to 25 minutes with only one. This is clearly unacceptable.

At first glance it would appear that the divergent results from similar workloads are inconsistent, but a closer look at the data explains the apparent discrepancy. The $E(t_s)$, mean briefing time, for the 9/1/77 data is 1.7 minutes, while the mean briefing time for 8/30/77 period is 5.26 minutes. This leads to an r, utilization, for one specialist of 0.229 and 0.789, respectively. As previously mentioned, once r gets above 0.7, extremely long queues and waiting times are a distinct possibility.

Another way of looking at the same data is to consider how many additional transactions might be conducted with the same number of specialists. This is more nearly in line with the basic objective for the FSS Automation Program of providing for future aviation growth without inordinate increases in personnel.

This analysis is based on taking the three busiest hours and the actual number of specialists available at the three separate facilities, rounded off to the lower whole number, and applying the model to see what the impact of additional traffic would be in a consolidated facility. Number of delays and average waiting times are computed for additional traffic of 10, 20, 30, 40, and 50 percent in table 12.

The predictions are interesting in several respects. First, the number of delays increases with the demand. This is so because the number of delays is the product of demand and the probability of a delay, which also increases with demand but at a lower rate at moderate utilization levels. Second, while the number of delays is

TABLE 7. SUMMARY ANALYSIS FOR 8/26/77, 1000 (HIGH ACTIVITY)

Average number of specialists available

IND - 4.0	HUF - 1.33	FWA - 2.83	Total - 8.16

Number of transactions

IND - 39	HUF - 19	FWA - 16	Total - 74

Average time per briefing (minutes)

IND - 2.61	HUF - 1.83	FWA - 2.85	Total - 2.46

<u>7 Specialists</u>	IND 4	4.2 delays averaging 1.13 minutes
	HUF 2	2.5 delays averaging 0.13 minutes
	FWA 1	12.2 delays averaging 11.88 minutes
	Total 7	18.9 delays averaging 7.89 minutes
	IND 4	4.2 delays averaging 1.13 minutes
	HUF 1	11.0 delays averaging 4.35 minutes
	FWA 2	3.3 delays averaging 2.30 minutes
	Total 7	18.5 delays averaging 3.25 minutes
	IND 3	12.6 delays averaging 2.00 minutes
	HUF 2	2.5 delays averaging 0.13 minutes
	FWA 2	3.3 delays averaging 2.30 minutes
	Total 7	18.4 delays averaging 1.80 minutes
	Consolidated 7	3.0 delays averaging 0.62 minutes

TABLE 7. SUMMARY ANALYSIS FOR 8/26/77, 1000 (HIGH ACTIVITY) (Continued)

6 Specialists	IND 4	4.2 delays averaging 1.13 minutes	
	HUF 1	11.0 delays averaging 4.35 minutes	
	FWA 1	12.2 delays averaging 11.88 minutes	
	Total 6	27.4 delays averaging 7.21 minutes	
	IND 3	12.2 delays averaging 2.00 minutes	
	HUF 1	11.0 delays averaging 4.35 minutes	
	FWA 2	3.3 delays averaging 2.30 minutes	
	Total 6	26.5 delays averaging 3.01 minutes	
	IND 3	12.2 delays averaging 2.00 minutes	
	HUF 2	2.5 delays averaging 0.13 minutes	
	FWA 1	12.2 delays averaging 11.88 minutes	
	Total 6	26.9 delays averaging 6.31 minutes	
	IND 2	30.4 delays averaging 8.60 minutes	
	HUF 2	2.5 delays averaging 0.13 minutes	
	FWA 2	3.3 delays averaging 02.3 minutes	
	Total 6	36.2 delays averaging 07.4 minutes	
	Consolidated 6	7.7 delays averaging 0.83 minutes	
5 Specialists			
	Consolidated 5	18.1 delays averaging 1.25 minutes	
4 Specialists			
	Consolidated 4	38.9 delays averaging 2.55 minutes	

TABLE 8. SUMMARY ANALYSIS FOR 8/25/77, 1400 (MODERATE ACTIVITY)

Average number of specialists available

IND - 2.00 HUF - 2.92 FWA - 1.58

Number of transactions

IND - 31 HUF - 13 FWA - 14

Average time per briefing (minutes)

IND - 1.79 HUF - 1.32 FWA - 1.76

<u>7 Specialists</u>	IND 3	2.3 delays averaging 0.86 minutes
	HUF 2	0.5 delays averaging 0.77 minutes
	FWA 2	0.1 delays averaging 1.11 minutes
	Total 7	2.9 delays averaging 0.85 minutes
<u>6 Specialists</u>	IND 2	9.1 delays averaging 1.68 minutes
	HUF 2	0.5 delays averaging 0.77 minutes
	FWA 2	0.1 delays averaging 1.11 minutes
	Total 6	9.7 delays averaging 1.63 minutes
	Consolidated 6	0.4 delays averaging 0.38 minutes
<u>5 Specialists</u>	IND 3	2.3 delays averaging 0.86 minutes
	HUF 1	3.7 delays averaging 1.85 minutes
	FWA 1	5.8 delays averaging 2.99 minutes
	Total 5	11.8 delays averaging 2.21 minutes
	Consolidated 5	1.57 delays averaging 0.49 minutes
<u>4 Specialists</u>	IND 2	9.1 delays averaging 1.68 minutes
	HUF 1	3.7 delays averaging 1.85 minutes
	FWA 1	5.8 delays averaging 1.11 minutes
	Total 4	18.6 delays averaging 1.54 minutes
	Consolidated 4	5.5 delays averaging 0.71 minutes
<u>3 Specialists</u>		
	Consolidated 3	16.4 delays averaging 1.22 minutes
<u>2 Specialists</u>		
	Consolidated 2	42.2 delays averaging 4.47 minutes

TABLE 9. SUMMARY ANALYSIS FOR 8/25/77, 1500
(MODERATE ACTIVITY)

Average number of specialists available

IND - 2.00	HUF - 2.58	FWA - 1.58

Number of transactions

IND - 29	HUF - 12	FWA - 9

7 Specialists	IND 3	1.8	delays averaging 0.83 minutes
	HUF 2	0.5	delays averaging 0.86 minutes
	FWA 2	0.3	delays averaging 1.08 minutes
	Total 7	2.6	delays averaging 0.86 minutes
6 Specialists	IND 2	7.4	delays averaging 1.55 minutes
	HUF 2	0.5	delays averaging 0.86 minutes
	FWA 2	0.3	delays averaging 1.08 minutes
	Total 6	8.2	delays averaging 1.49 minutes
	Consolidated 6	0.20	delays averaging 0.38 minutes
5 Specialists	IND 3	1.8	delays averaging 0.83 minutes
	HUF 1	3.5	delays averaging 2.08 minutes
	FWA 1	2.5	delays averaging 2.58 minutes
	Total 5	7.8	delays averaging 1.95 minutes
	Consolidated 5	0.85	delays averaging 0.48 minutes
4 Specialists	IND 2	7.4	delays averaging 1.55 minutes
	HUF 1	4.1	delays averaging 2.08 minutes
	FWA 1	2.5	delays averaging 2.58 minutes
	Total 4	14.0	delays averaging 1.89 minutes
	Consolidated 4	3.2	delays averaging 0.67 minutes
3 Specialists	IND 1	24.8	delays averaging 12.25 minutes
	HUF 1	4.1	delays averaging 2.08 minutes
	FWA 1	2.5	delays averaging 2.58 minutes
	Total 3	31.4	delays averaging 10.15 minutes
	Consolidated 3	10.5	delays averaging 1.69 minutes

TABLE 10. SUMMARY ANALYSIS FOR 8/30/77, 0400 (LOW ACTIVITY)

Average number of specialists available

IND - 1 HUF - .92 FWA - .92

Number of transactions

IND - 5 HUF - 1 FWA - 3

<u>3 Specialists</u>	IND 1	2.4 delays averaging 10.97 minutes
	HUF 1	0.1 delays averaging 7.57 minutes
	FWA 1	0.6 delays averaging 5.00 minutes
	Total 3	3.1 delays averaging 9.67 minutes
	Consolidated 3	0.45 delays averaging 2.38 minutes
<u>2 Specialists</u>		
	Consolidated 2	2.01 delays averaging 4.34 minutes
<u>1 Specialist</u>		
	Consolidated 1	7.10 delays averaging 24.93 minutes

TABLE 11. SUMMARY ANALYSIS FOR 9/1/77, 0000 (LOW ACTIVITY)

Average number of specialists available

IND - 1.0 HUF - 1.0 FWA - .92

Number of transactions

IND - 6 HUF - 1 FWA - 1

<u>3 Specialists</u>	IND 1	0.1 delays averaging 1.17 minutes
	HUF 1	0.02 delays averaging 1.19 minutes
	FWA 1	0.09 delays averaging 6.2 minutes
	Total 3	0.21 delays averaging 3.52 minutes
	Consolidated 3	0.02 delays averaging 0.62 minutes
<u>2 Specialists</u>		
	Consolidated 2	0.19 delays averaging 0.97 minutes
<u>1 Specialist</u>		
	Consolidated 1	1.8 delays averaging 2.22 minutes

TABLE 12. IMPACT OF ADDITIONAL DEMAND ON CONSOLIDATED FACILITIES

8/26/77, 1000

Actual number of transactions 74

Actual number of specialists available in 3 facilities 8.16

Model prediction for 7 specialists in consolidated facility:

74 trans,		3.0	delays averaging	0.62	minutes.
81 trans,	(+10%),	4.9	delays averaging	0.67	minutes
89 trans,	(+20%),	8.1	delays averaging	0.73	minutes
96 trans,	(+30%),	12.1	delays averaging	0.80	minutes
104 trans,	(+40%),	18.2	delays averaging	0.90	minutes
111 trans,	(+50%),	25.2	delays averaging	1.00	minutes

8/30/77, 0700

Actual number of transactions 87

Actual number of specialists available in 3 facilities 7.6

Model prediction for 7 specialists, consolidated facility:

87 trans,		7.3	delays averaging	0.72	minutes
96 trans,	(+10%),	12.3	delays averaging	0.81	minutes
104 trans,	(+20%),	18.5	delays averaging	0.91	minutes
113 trans,	(+30%),	27.9	delays averaging	1.11	minutes
122 trans,	(+40%),	40.3	delays averaging	1.25	minutes
131 trans,	(+50%),	55.8	delays averaging	1.54	minutes

8/25/77, 1400

Actual number of transactions 58

Actual number of specialists available in 3 facilities 6.5

Model prediction for 6 specialists, consolidated facility:

58 trans,		0.4	delays averaging	0.38	minutes
64 trans,	(+10%),	0.7	delays averaging	0.40	minutes
70 trans,	(+20%),	1.1	delays averaging	0.42	minutes
75 trans,	(+30%),	1.7	delays averaging	0.43	minutes
81 trans,	(+40%),	2.5	delays averaging	0.45	minutes
87 trans,	(+50%),	3.7	delays averaging	0.47	minutes

going up slightly faster than demand, time of delay is still moderate, even after a 50 percent increase in demand. Finally, the time of delay, even with a 50 percent increase in demand, is less than that for the same number of specialists in separate facilities. Again, all the limitations of the model apply to this analysis as well.

The above data, taken as a whole, provide a vivid demonstration of the advantages of multiserver queues described at the beginning of this section. The model precludes the possibility that there could be anything but an improvement. Nevertheless, it would be dangerous to accept the data without paying particular attention to the assumptions required. Our observations in the facility make it clear that the specialists do not always answer the next call as soon as they finish the previous one. Nor is it likely that they take, on the average, the same amount of time to give a briefing. It also seems probable that briefings tend to be shortened during busy periods and lengthened during off-peak hours.

The big advantage of consolidation is that it eliminates the possibility of having servers in one location with nothing to do while users are waiting somewhere else for a busy server to become available. To the extent the servers see the intervals between successive calls in the present system as "their time," they may not go from call to call with zero interval as the model requires. Of course, it is always possible to add some "rest time" to the "service time" to account for this, but it should be noted that workload predictions at higher utilization levels are very sensitive to even small changes in service time.

Two additional caveats are in order in interpreting this data. The first is the assumption that "consolidation" has no effect on the servers' ability to provide information, or for that matter, on the time required to provide information. It presumes not only access to all the necessary data, but also that it will not take any longer to provide the same briefing over a larger geographical area than a smaller one. Maloney's report (reference 1) shows that 40 to 50 percent of pre-flight briefings are local; i.e., less than 100 miles. One would expect that each additional local briefing would demand less time to study the weather than the previous one. In a consolidated system of air route traffic control center (ARTCC) size, for example, there would be well over 16 of these "local" areas. This would seem to require more frequent reference to the data base. It would also imply some loss of the kind of highly specialized information about the local area that did not find its way into the data base, although it is not clear at this time what that loss might mean.

The other point that must be made about this data is that consolidation in the sense of the queuing model--which is the sole reference of this analysis--does not require physical colocation. It merely means equal access to all servers, and there are a number of ways this can be accomplished. In colocation, all incoming calls would come to a call director which would then distribute them to available specialists at that location. This function might also be performed by having the call director reroute the call to the nearest FAA if all local briefers are busy.

The data collected do not tell us how many people called one of the FSS's and got a busy signal and consequently made their flight without a weather briefing or obtained their weather briefing from another source. The data do not provide the number of lost calls that called back later and were then counted as completed transactions. Finally, the data do not tell us, if we were to consolidate, how many additional users would be generated simply due to the improved service and thus bring the queues and delays up to the present nonconsolidated level.

There is comparatively little information in the data to tell the system designer how to make improvements. Martin's introduction (reference 4) sums up the problems:

"Frequently, one sees systems today in which these calculations are not done, or they are done in a short-sighted manner. Indeed, in many systems they are not straightforward calculations because there are intricate trade-offs between one aspect of the design and another--trade-offs, for example, between line cost and logic cost; between system centralization and decentralization; between response time and network complexity; between data accuracy and transmission speed; and between network cost and psychological considerations in the man-machine dialogue. The trade-offs that involve user psychology are subjective. They can only be made confidently by a systems analyst who is experienced, and probably also well read, in the art of designing man-computer dialogue."

CONCLUSIONS

The data reported here on the Indianapolis, Terre Haute, and Fort Wayne FSS's provide a way of estimating the effect of consolidation on preflight briefing given the level of service and the technology in the fall of 1977. It must be remembered that consolidation implies no more than giving the user accessibility to all available servers whether they are located at one facility or widely separated facilities. This can be accomplished by either colocating the facilities (physical consolidation) or by integrating the communication network (functional consolidation). This data clearly supports the expected value of consolidation and must be regarded as an encouraging indication that the present system can be made to operate more efficiently and provide better service to the users.

Specifically, the conclusions inferred from the results are:

1. Consolidation will produce equal service with fewer personnel or better service with the same personnel.

2. Given the present staffing, a 50 percent increase in demand could be accommodated without any increase in time spent waiting for service, although more callers may have to wait.

3. Consolidation will produce a more equitable distribution of workload among the personnel consolidated.

4. Given the more equitable distribution of workload produced by consolidation, each specialist can work at a level closer to his optimum capability (servicing more pilots in a given period of time).

5. With consolidation and the present staffing, more calls will be processed and fewer calls will be lost. Shorter waits mean fewer lost calls.

6. Consolidation can reduce (a) the likelihood of a given call being delayed and (b) the duration of waiting time if a call is delayed.

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2. Talotta, J. D., and Maloney, J. J., A Comparison of Facility Operation at the Washington Flight Service Station Before and After Consolidation, NAFEC Letter Report, NA-78-42-LR, April 1979.

3. Maloney, J. J., and Talotta, J. D., Analysis of Flight Service Station Consolidation and Sectorization - Phase II: Las Vegas, Tonopah, Ely, and Needles Flight Service Stations, NAFEC Letter Report NA-78-25-LR, June 1978.

4. Martin, James, Systems Analysis for Data Transmission, Englewood Cliffs, N.J., Prentice-Hall, Inc., 1972, pp. 413-480.

APPENDIX A

QUEUING FORMULA CALCULATIONS

$E(n)$ = mean number of calls/hour

$E(t_s)$ = mean service time in minutes

M = number of servers (specialists)

N = number of transactions

$$r = \frac{E(n) \times E(t_s)}{M \times 60}$$

$$E(w) = \frac{B \times r}{(1 - r)}$$

$$E(q) = E(w) + Nr$$

$$E(t_w) = \frac{B \times E(t_s)}{N(1 - r)}$$

$$E(t_q) = E(t_w) + E(t_s)$$

$$E(t_d) = \frac{E(t_w)}{B}$$

$$B = \left\{ 1 - \left(\frac{\sum_{N=0}^{M-1} \frac{(M\rho)^N}{N!}}{\sum_{N=0}^{M} \frac{(M\rho)^N}{N!}} \right) \right\} \Bigg/ \left\{ 1 - \rho \left(\frac{\sum_{N=0}^{M-1} \frac{(M\rho)^N}{N!}}{\sum_{N=0}^{M} \frac{(M\rho)^N}{N!}} \right) \right\}$$

SR-52 program for computation of above parameters:

Starting Address		Comments
000	lbl A sto 01 stflg 1 hlt	no. trans/hour
008	lbl B sto 02 stflg 1 hlt	$E(t_s)$
016	lbl C sto 03 stflg 1 sto 00 hlt	M
027	lbl E ifflg 1 tan rcl 05 x rcl 03 = sto 06 y^x rcl 00 / rcl 00! = sto 07 sto 08	compute B
059	lbl sin 1 inv sum 00 rcl 06 y^x rcl 00 / rcl 00! = sum 08 rcl 00 inv ifzro sin (1-((rcl 08 - rcl 07) / rcl 08) sto 09) / (1 - rcl 05 x rcl 09) = sto 10 hlt	
127	lbl tan rcl 01 x rcl 02/ 60 / rcl 03 = sto 05 inv stflg 1 gto 035	compute r
154	lbl A' rcl 10 x rcl 05 / (1 - rcl 05) = sto 11 hlt	compute E(w)
176	lbl B' rcl 11 + rcl 03 x rcl 05 = hlt	compute E(q)
191	lbl C' rcl 10 x rcl 02 / rcl 03 / (1 - rcl 05) = sto 12 hlt	compute $E(t_w)$

C' + rcl 02 = average time in queue $E(t_q)$

C' / rcl 10 = average time for those delayed $E(t_d)$

registers:

01 - trans in 1 hour

02 - avg serv time

03 - no. of servers

04 - not used

05 - r

06 - m x r

07 - $(m \times r)^M/M!$

08 - sum $\frac{(N \times r)^N}{N}$

09 - used

10 - B

11 - E(w)

12 - $E(t_w)$

APPENDIX B

QUEUING MODEL APPLICATION FORM

LOCATION: IND
DATE: 8/30/77, 0700
WX: IFR

A.	Number of servers M	5(3.67)	4	3
B.	Number of transactions N	57		
C.	Average serving time* $E(t_s)$	2.46		
D.	Observed waiting time (sec)	54.24		
E.	Number of calls delayed E(w)	40		
F.	Average time of delay (sec)	82.2		
G.	Number of calls lost	5		
H.	Probability of waiting B (E)	0.1036	0.2673	0.6134
I.	Utilization r (05)	.467	.584	.779
J.	Intensity M x r (06)	2.337	2.337	2.337
K.	Average number waiting E(w) (A')	.091	.376	2.162
L.	Average number in queue E(q) (B')	2.428	2.713	4.499
M.	Average time* waiting $E(t_w)$ (C')	.096	.395	2.276
N.	Average time* in queue $E(t_q)$ (C'+02)	2.556	2.855	4.736
O.	Average time* for those $E(t_d)$ delayed (C'/10)	.924	1.479	3.710

*Minutes

QUEUING MODEL APPLICATION FORM

LOCATION: HUF
DATE: 8/30/77, 0700
WX: IFR

A.	Number of servers M	2(1.42)	1
B.	Number of transactions N	15	
C.	Average serving time $E(t_s)$	2.28	
D.	Observed waiting time* (sec)	67.3	
E.	Number of calls delayed E(w)	14	
F.	Average time of delay (sec)	95.79	
G.	Number of calls lost	5	
H.	Probability of waiting B (E)	0.1264	0.5700
I.	Utilization r (05)	.285	.570
J.	Intensity M x r (06)	.570	.570
K.	Average number waiting E(w) (A')	.050	.756
L.	Average number in queue E(q) (B')	.620	1.326
M.	Average time* waiting $E(t_w)$ (C')	.202	3.022
N.	Average time* in queue $E(t_q)$ (C'+02)	2.482	5.302
O.	Average time* for those $E(t_d)$ delayed (C'/10)	1.594	5.302

*Minutes

QUEUING MODEL APPLICATION FORM

LOCATION: FWA
DATE: 8/30/77, 0700
WX: IFR

A.	Number of servers M	3(2.5)	2	1
B.	Number of transactions N	15		
C.	Average serving time* $E(t_s)$	3.57		
D.	Observed waiting time (sec)	9.6		
E.	Number of calls delayed E(w)	2		
F.	Average time of delay (sec)	43.5		
G.	Number of calls lost	0		
H.	Probability of waiting B (E)	0.0686	0.2754	0.8925
I.	Utilization r (05)	.298	.446	.893
J.	Intensity M x r (06)	.893	.893	.893
K.	Average number waiting E(w) (A')	.029	.222	7.410
L.	Average number in queue E(q) (B')	.922	1.114	8.302
M.	Average time* waiting $E(t_w)$ (C')	.116	.888	29.639
N.	Average time* in queue $E(t_q)$ (C'+02)	3.686	4.458	33.209
O.	Average time* for those $E(t_d)$ delayed (C'/10)	1.694	3.224	33.209

*Minutes

QUEUING MODEL APPLICATION FORM

LOCATION: Consolidated
DATE: 8/30/77, 0700
WX: IFR

A.	Number of servers M	7(7.59)	6	5	4
B.	Number of transactions N	87			
C.	Average serving time* $E(t_s)$	2.62			
D.	Observed waiting time (sec)	53.92			
E.	Number of calls delayed E(w)	57			
F.	Average time of delay (sec)	84.6			
G.	Number of calls lost	10			
H.	Probability of waiting B (E)	0.1088	0.2382	0.4794	0.8912
I.	Utilization r (05)	.543	.633	.760	.950
J.	Intensity M x r (06)	3.799	3.799	3.799	3.799
K.	Average number waiting E(w) (A')	.129	.411	1.517	16.887
L.	Average number in queue E(q) (B')	3.929	4.211	5.317	20.687
M.	Average time* waiting $E(t_w)$ (C')	.089	.284	1.046	11.647
N.	Average time* in queue $E(t_q)$ (C'+02)	2.709	2.904	3.667	14.267
O.	Average time* for those delayed $E(t_d)$ (C'/10)	.819	1.191	2.183	13.069

*Minutes

DATA SUMMARY FOR 8/30/77, 0700

SERVERS		7	6	5	4	3	2	1*
IND	% who wait			10.4%	26.7%	61.3%		
(57)	time they wait			.92 min	1.48 min	3.71 min		
t_s = 2.46	% utiliz.			46.7%	58.4%	77.9%		
HUF	% who wait						12.6%	57.0%
(15)	time they wait						1.59 min	5.30 min
t_s = 2.28	% utiliz.						28.5%	57.0%
FWA	% who wait					6.9%	27.5%	89.2%
(15)	time they wait					1.69 min	3.22 min	33.21 min
t_s = 3.57	% utiliz.					29.8%	44.6%	89.2%
CONS	% who wait	10.88%	23.82%	47.94%	89.12%			
(87)	time they wait	.82 min	1.19 min	2.18 min	13.07 min			
t_s = 2.47	% utiliz.	54.3%	63.3%	76.0%	95.0%			

8/30/77, 0700 worst case, 87 transactions, 10 lost calls

to evaluate "consolidation," compare "x" servers under CONS with any combination from IND, HUF, and FWA that add up to "x." t_s is the average time to service one call; it varies with weather conditions.

% who wait: percent of callers who are put of "hold" or receive a busy signal
time waiting: average time of wait, considering only those who have to wait
% utiliz: percent of servers time spent in providing service.

*With one server, % utilization equals probability of getting a busy signal

QUEUING MODEL APPLICATION FORM

LOCATION: IND
DATE: 8/26/77, 1000
WX: MVFR

A.	Number of servers M	4(4.0)	3	2
B.	Number of transactions N	39		
C.	Average serving time* $E(t_s)$	2.61		
D.	Observed waiting time (sec)	20.1		
E.	Number of calls delayed E(w)	11		
F.	Average time of delay (sec)	69.2		
G.	Number of calls lost	1		
H.	Probability of waiting B (E)	0.108	0.312	0.779
I.	Utilization r (05)	.424	.566	.848
J.	Intensity M x r (06)	1.697	1.697	1.697
K.	Average number waiting E(w) (A')	.080	.406	4.352
L.	Average number in queue E(q) (B')	1.776	2.102	6.049
M.	Average time* waiting $E(t_w)$ (C')	.122	.624	6.696
N.	Average time* in queue $E(t_q)$ (C'+02)	2.732	3.234	9.306
O.	Average time* for those $E(t_d)$ delayed (C'/10)	1.133	2.002	8.600

*Minutes

QUEUING MODEL APPLICATION FORM

LOCATION: HUF
DATE: 8/26/77, 1000
WX: IFR

A.	Number of servers M	2(1.33)	1
B.	Number of transactions N	19	
C.	Average serving time* $E(t_s)$	1.83	
D.	Observed waiting time (sec)	6.63	
E.	Number of calls delayed E(w)	3	
F.	Average time of delay (sec)	22.0	
G.	Number of calls lost	0	
H.	Probability of waiting B (E)	0.1302	0.5795
I.	Utilization r (05)	.290	.580
J.	Intensity M x r (06)	.580	.580
K.	Average number waiting E(w) (A')	.053	.799
L.	Average number in queue E(q) (B')	.663	1.378
M.	Average time* waiting $E(t_w)$ (C')	.168	2.522
N.	Average time* in queue $E(t_q)$ (C'+02)	1.998	4.352
O.	Average time* for those $E(t_d)$ delayed (C'/10)	.130	4.352

*Minutes

QUEUING MODEL APPLICATION FORM

LOCATION: FWA
DATE: 8/26/77, 1000
WX: VFR

A.	Number of servers M	3(2.83)	2	1
B.	Number of transactions N	16		
C.	Average serving time* $E(t_s)$	2.85		
D.	Observed waiting time (sec)	4.81		
E.	Number of calls delayed E(w)	1		
F.	Average time of delay (sec)	33		
G.	Number of calls lost	0		
H.	Probability of waiting B (E)	0.0456	0.2093	0.7600
I.	Utilization r (05)	.2533	.3800	.7600
J.	Intensity M x r (06)	.7600	.7600	.7600
K.	Average number waiting E(w) (A')	.016	.128	2.407
L.	Average number in queue E(q) (B')	.776	.888	3.167
M.	Average time* waiting $E(t_w)$ (C')	.058	.481	9.025
N.	Average time* in queue $E(t_q)$ (C'+02)	2.908	3.331	11.875
O.	Average time* for those $E(t_d)$ delayed (C'/10)	1.272	2.298	11.875

*Minutes

QUEUING MODEL APPLICATION FORM

LOCATION: Consolidated
DATE: 8/26/77, 1000

A.	Number of servers M	7(8.16)	6	5	4
B.	Number of transactions N	74			
C.	Average serving time* $E(t_s)$	2.46			
D.	Observed waiting time (sec)	14.6			
E.	Number of calls delayed E(w)	16			
F.	Average time of delay (sec)	57.5			
G.	Number of calls lost	0			
H.	Probability of waiting B (E)	0.0398	0.1039	0.2452	0.5246
I.	Utilization r (05)	.434	.506	.607	.759
J.	Intensity M x r (06)	3.036	3.036	3.036	3.036
K.	Average number waiting E(w) (A')	.031	.106	.379	1.652
L.	Average number in queue E(q) (B')	3.067	3.142	3.415	4.688
M.	Average time* waiting $E(t_w)$ (C')	.025	.086	.307	1.340
N.	Average time* in queue $E(t_q)$ (C'+02)	2.486	2.548	2.759	2.462
O.	Average time* for those delayed $E(t_d)$ (C'/10)	.621	.831	1.253	2.554

*Minutes

DATA SUMMARY FOR 8/26/77, 1000

SERVERS		7	6	5	4	3	2	1*
IND	% who wait				10.8%	32.3%	77.9%	
(39)	time they wait				1.13 min	2.00 min	8.6 min	
t_s = 2.61	% utiliz.				42.4%	56.6%	84.8%	
HUF	% who wait						13.0%	58.0%
(19)	time they wait						.13 min	4.35 min
t_s = 1.83	% utiliz.						2.90%	58.0%
FWA	% who wait					4.6%	20.9%	76.0%
(16)	time they wait					1.27 min	2.3 min	11.88 min
t_s = 2.85	% utiliz.					25.3%	38.0%	76.0%
CONS	% who wait	4.0%	10.4%	24.5%	52.5%			
(74)	time they wait	.62 min	.83 min	1.25 min	2.55 min			
t_s = 2.46	% utiliz.	43.4%	50.6%	60.7%	75.9%			

8/26/77, 1000   74 transactions, 1 lost call

to evaluate "consolidation," compare "x" servers under CONS with any combination from IND, HUF, and FWA that add up to "x." t_s is the average time to service one call; it varies with weather conditions.

% who wait: percent of callers who are put of "hold" or receive a busy signal
time waiting: average time of wait, considering only those who have to wait
% utiliz: percent of servers time spent in providing service.

*With one server, % utilization equals probability of getting a busy signal

QUEUING MODEL APPLICATION FORM

LOCATION: IND
DATE: 8/25/77, 1400
WX: VFR

A.	Number of servers M	3(2.00)	2	1
B.	Number of transactions N	31		
C.	Average serving time* $E(t_s)$	1.79		
D.	Observed waiting time (sec)	29.6		
E.	Number of calls delayed E(w)	11		
F.	Average time of delay (sec)	108.3		
G.	Number of calls lost	10		
H.	Probability of waiting B (E)	0.0749	0.2924	0.9248
I.	Utilization r (05)	.308	.460	.925
J.	Intensity M x r (06)	.925	.925	.925
K.	Average number waiting E(w) (A')	.033	.250	11.379
L.	Average number in queue E(q) (B')	.958	1.18	12.304
M.	Average time* waiting $E(t_w)$ (C')	.065	.49	22.024
N.	Average time* in queue $E(t_q)$ (C'+02)	1.855	2.28	23.814
O.	Average time* for those delayed $E(t_d)$ (C'/10)	.863	1.68	23.814

*Minutes

QUEUING MODEL APPLICATION FORM

LOCATION: HUF
DATE: 8/25/77, 1400
WX: VFR

A.	Number of servers M	3(2.92)	2	1
B.	Number of transactions N	13		
C.	Average serving time* $E(t_s)$	1.32		
D.	Observed waiting time (sec)	8.46		
E.	Number of calls delayed E(w)	5		
F.	Average time of delay (sec)	15.6		
G.	Number of calls lost	0		
H.	Probability of waiting B (E)	0.0032	0.0358	0.2860
I.	Utilization r (05)	.095	.143	.286
J.	Intensity M x r (06)	.286	.286	.286
K.	Average number waiting E(w) (A')	0	.006	115
L.	Average number in queue E(q) (B')	.286	.292	.401
M.	Average time* waiting $E(t_w)$ (C')	.002	.028	.529
N.	Average time* in queue $E(t_q)$ (C'+02)	1.32	1.35	1.849
O.	Average time* for those $E(t_d)$ delayed (C'/10)	.486	.770	1.849

*Minutes

QUEUING MODEL APPLICATION FORM

LOCATION: FWA
DATE: 8/25/77, 1400
WX: VFR

A.	Number of servers M	2(1.58)	1
B.	Number of transactions N	14	
C.	Average serving time* $E(t_s)$	1.76	
D.	Observed waiting time (sec)	12.1	
E.	Number of calls delayed E(w)	5	
F.	Average time of delay (sec)	24.6	
G.	Number of calls lost	0	
H.	Probability of waiting B (E)	0.0700	0.411
I.	Utilization r (05)	.205	.411
J.	Intensity M x r (06)	.411	.411
K.	Average number waiting E(w) (A')	.018	.286
L.	Average number in queue E(q) (B')	.429	.697
M.	Average time* waiting $E(t_w)$ (C')	.078	1.226
N.	Average time* in queue $E(t_q)$ (C'+02)	1.84	2.986
O.	Average time* for those $E(t_d)$ delayed (C'/10)	1.107	2.986

*Minutes

QUEUING MODEL APPLICATION FORM

LOCATION: Consolidated
DATE: 8/25/77, 1400

A.	Number of servers M	6(6.5)	5	4	3	2
B.	Number of transactions N	58				
C.	Average serving time* $E(t_s)$	1.68				
D.	Observed waiting time (sec)	26.2				
E.	Number of calls delayed E(w)	21				
F.	Average time of delay (sec)	68.9				
G.	Number of calls lost	10				
H.	Probability of waiting B (E)	0.0069	0.0270	0.0950	0.2830	0.728
I.	Utilization r (05)	.271	.325	.406	.541	.812
J.	Intensity M x r (06)	1.624	1.624	1.624	1.624	1.624
K.	Average number waiting E(w) (A')	.003	.013	.065	.334	3.143
L.	Average number in queue E(q) (B')	1.627	1.637	1.689	1.958	4.767
M.	Average time* waiting $E(t_w)$ (C')	.003	.014	.067	.346	3.252
N.	Average time* in queue $E(t_q)$ (C'+02)	1.683	1.694	1.747	2.026	4.932
O.	Average time* for those delayed $E(t_d)$ (C'/10)	.384	.498	.707	1.221	4.468

*Minutes

DATA SUMMARY FOR 8/25/77, 1400

SERVERS		6	5	4	3	2	1*
IND	% who wait				7.5%	29.2%	92.5%
(31)	time they wait				0.86 min	1.68 min	23.81 min
t_s = 1.79	% utiliz.				30.8%	46%	92.5%
HUF	% who wait				0.3%	3.6%	28.6%
(13)	time they wait				0.49 min	0.77 min	1.85 min
t_s = 1.32	% utiliz.				9.5%	14.3%	28.6%
FWA	% who wait					0.7%	41.1%
(14)	time they wait					1.11 min	2.99 min
t_s = 1.76	% utiliz.					20.5%	41.1%
CONS	% who wait	0.7%	2.7%	9.5%	28.3%	72.8%	
(58)	time they wait	0.38 min	0.50 min	0.71 min	1.22 min	4.47 min	
t_s = 1.67	% utiliz.	27.1%	32.5%	40.6%	54.1%	81.2%	

8/25/77, 1400   58 transactions, 10 lost calls

to evaluate "consolidation," compare "x" servers under CONS with any combination from IND, HUF, and FWA that add up to "x." t_s is the average time to service one call; it varies with weather conditions.

% who wait: percent of callers who are put of "hold" or receive a busy signal
time waiting: average time of wait, considering only those who have to wait
% utiliz: percent of servers time spent in providing service.

*With one server, % utilization equals probability of getting a busy signal

QUEUING MODEL APPLICATION FORM

LOCATION: IND
DATE: 8/25/77, 1500
WX: VFR

A.	Number of servers M	3(2.0)	2	1
B.	Number of transactions N	29		
C.	Average serving time* $E(t_s)$	1.77		
D.	Observed waiting time (sec)	22.2		
E.	Number of calls delayed E(w)	9		
F.	Average time of delay (sec)	68.8		
G.	Number of calls lost	0		
H.	Probability of waiting B (E)	0.0617	0.2566	0.856
I.	Utilization r (05)	.285	.430	.856
J.	Intensity M x r (06)	.856	.856	.856
K.	Average number waiting E(w) (A')	.025	.190	5.065
L.	Average number in queue E(q) (B')	.880	1.05	5.920
M.	Average time* waiting $E(t_w)$ (C')	.051	.400	10.479
N.	Average time* in queue $E(t_q)$ (C'+02)	1.821	2.170	12.249
O.	Average time* for those $E(t_d)$ delayed (C'/10)	.825	1.550	12.249

*Minutes

QUEUING MODEL APPLICATION FORM

LOCATION: HUF
DATE: 8/25/77, 1500
WX: VFR

A.	Number of servers M	3(2.58)	2	1
B.	Number of transactions N	12		
C.	Average serving time* $E(t_s)$	1.47		
D.	Observed waiting time (sec)	17.5		
E.	Number of calls delayed E(w)	5		
F.	Average time of delay (sec)	45.8		
G.	Number of calls lost	3		
H.	Probability of waiting B (E)	0.0035	0.0377	0.2940
I.	Utilization r (05)	.098	.147	.294
J.	Intensity M x r (06)	.294	.294	.294
K.	Average number waiting E(w) (A')	0	.007	.122
L.	Average number in queue E(q) (B')	.294	.301	.416
M.	Average time* waiting $E(t_w)$ (C')	.002	.033	.612
N.	Average time* in queue $E(t_q)$ (C'+02)	1.472	1.503	2.082
O.	Average time* for those $E(t_d)$ delayed (C'/10)	.543	.862	2.082

*Minutes

QUEUING MODEL APPLICATION FORM

LOCATION: FWA
DATE: 8/25/77, 1500
WX: VFR

A.	Number of servers M	2(1.58)	1
B.	Number of transactions N	9	
C.	Average serving time* $E(t_s)$	1.86	
D.	Observed waiting time (sec)	10.3	
E.	Number of calls delayed E(w)	3	
F.	Average time of delay (sec)	23.3	
G.	Number of calls lost	0	
H.	Probability of waiting B (E)	0.0342	0.279
I.	Utilization r (05)	.140	.279
J.	Intensity M x r (06)	.279	.279
K.	Average number waiting E(w) (A')	.006	.108
L.	Average number in queue E(q) (B')	.285	.387
M.	Average time* waiting $E(t_w)$ (C')	.037	.720
N.	Average time* in queue $E(t_q)$ (C'+02)	1.897	2.580
O.	Average time* for those $E(t_d)$ delayed (C'/10)	1.081	2.580

*Minutes

QUEUING MODEL APPLICATION FORM

LOCATION: Consolidated
DATE: 8/25/77, 1500

A.	Number of servers M	6(6.17)	5	4	3	2
B.	Number of transactions N	50				
C.	Average serving time* $E(t_s)$	1.714				
D.	Observed waiting time (sec)	18.9				
E.	Number of calls delayed E(w)	17				
F.	Average time of delay (sec)	55.1				
G.	Number of calls lost	3				
H.	Probability of waiting B (E)	0.0037	0.0166	0.0642	0.212	0.595
I.	Utilization r (05)	.238	.286	.357	.476	.714
J.	Intensity M x r (06)	1.428	1.428	1.428	1.428	1.428
K.	Average number waiting E(w) (A')	.012	.007	.036	.193	1.487
L.	Average number in queue E(q) (B')	1.430	1.435	1.464	1.621	2.915
M.	Average time* waiting $E(t_w)$ (C')	.001	.008	.043	.231	1.784
N.	Average time* in queue $E(t_q)$ (C'+02)	1.715	1.722	1.757	1.945	3.500
O.	Average time* for those $E(t_d)$ delayed (C'/10)	.375	.480	.667	1.091	2.998

*Minutes

DATA SUMMARY FOR 8/25/77, 1500

SERVERS		6	5	4	3	2	1*
IND	% who wait				6.2%	25.6%	85.6%
(29)	time they wait				0.83 min	1.55 min	12.25 min
t_s = 1.77	% utiliz.				28.5%	43.0%	85.6%
HUF	% who wait				0.35%	3.8%	29.4%
(12)	time they wait				0.54 min	0.86 min	2.08 min
t_s = 1.47	% utiliz.				9.8%	14.7%	29.4%
FWA	% who wait					3.4%	27.9%
(9)	time they wait					1.08 min	2.58 min
t_s = 1.86	% utiliz.					14.0%	27.9%
CONS	% who wait	0.4%	1.7%	6.4%	21.2%	59.5%	
(50)	time they wait	0.38 min	0.48 min	0.67 min	1.09 min	3.00 min	
t_s = 1.71	% utiliz.	23.8%	28.6%	35.7%	47.6%	71.4%	

8/25/77, 1500   50 transactions, 3 lost calls

to evaluate "consolidation," compare "x" servers under CONS with any combination from IND, HUF, and FWA that add up to "x." t_s is the average time to service one call; it varies with weather conditions.

% who wait: percent of callers who are put of "hold" or receive a busy signal
time waiting: average time of wait, considering only those who have to wait
% utiliz: percent of servers time spent in providing service.

*With one server, % utilization equals probability of getting a busy signal

QUEUING MODEL APPLICATION FORM

LOCATION: IND
DATE: 8/30/77, 0400
WX: IFR

A.	Number of servers M	1(1.0)
B.	Number of transactions N	5
C.	Average serving time* $E(t_s)$	5.73
D.	Observed waiting time (sec)	72.7
E.	Number of calls delayed E(w)	3
F.	Average time of delay (sec)	145.3
G.	Number of calls lost	1
H.	Probability of waiting B (E)	0.4775
I.	Utilization r (05)	.478
J.	Intensity M x r (06)	.478
K.	Average number waiting E(w) (A')	.436
L.	Average number in queue E(q) (B')	.914
M.	Average time* waiting $E(t_w)$ (C')	5.237
N.	Average time* in queue $E(t_q)$ (C'+02)	10.967
O.	Average time* for those delayed $E(t_d)$ (C'/10)	10.967

*Minutes

QUEUING MODEL APPLICATION FORM

LOCATION: HUF
DATE: 8/30/77, 0400
WX: IFR

A.	Number of servers M	1(.92)
B.	Number of transactions N	1
C.	Average serving time* $E(t_s)$	6.72
D.	Observed waiting time (sec)	22.0
E.	Number of calls delayed E(w)	1
F.	Average time of delay (sec)	22.0
G.	Number of calls lost	0
H.	Probability of waiting B (E)	0.1120
I.	Utilization r (05)	.112
J.	Intensity M x r (06)	.112
K.	Average number waiting E(w) (A')	.014
L.	Average number in queue E(q) (B')	.126
M.	Average time* waiting $E(t_w)$ (C')	.848
N.	Average time* in queue $E(t_q)$ (C'+02)	7.568
O.	Average time* for those $E(t_d)$ delayed (C'/10)	7.568

*Minutes

QUEUING MODEL APPLICATION FORM

LOCATION: FWA
DATE: 8/30/77, 0400
WX: MVFR

A.	Number of servers M	1(.92)
B.	Number of transactions N	3
C.	Average serving time* $E(t_s)$	4.00
D.	Observed waiting time (sec)	6.33
E.	Number of calls delayed E(w)	0
F.	Average time of delay (sec)	0
G.	Number of calls lost	0
H.	Probability of waiting B (E)	0.2000
I.	Utilization r (05)	.200
J.	Intensity M x r (06)	.200
K.	Average number waiting E(w) (A')	.050
L.	Average number in queue E(q) (B')	.250
M.	Average time* waiting $E(t_w)$ (C')	1.000
N.	Average time* in queue $E(t_q)$ (C'+02)	5.000
O.	Average time* for those $E(t_d)$ delayed (C'/10)	5.000

*Minutes

QUEUING MODEL APPLICATION FORM

LOCATION: Consolidated
DATE: 8/30/77, 0400

A.	Number of servers M	3(2.83)	2	1
B.	Number of transactions N	9		
C.	Average serving time* $E(t_s)$	5.26		
D.	Observed waiting time (sec)	47.8		
E.	Number of calls delayed E(w)	4		
F.	Average time of delay (sec)	114.8		
G.	Number of calls lost	0		
H.	Probability of waiting B (E)	0.0502	0.2232	0.7890
I.	Utilization r (05)	.263	.395	.789
J.	Intensity M x r (06)	.789	.789	.789
K.	Average number waiting E(w) (A')	.018	.145	2.950
L.	Average number in queue E(q) (B')	.807	.934	3.739
M.	Average time* waiting $E(t_w)$ (C')	.119	.969	19.669
N.	Average time* in queue $E(t_q)$ (C'+02)	5.379	6.229	24.929
O.	Average time* for those $E(t_d)$ delayed (C'/10)	2.379	4.344	24.929

*Minutes

DATA SUMMARY FOR 8/30/77, 0400

SERVERS		3	2	1*
IND	% who wait			47.8%
(5)	time they wait			10.97 min
t_s = 5.73	% utiliz.			47.8%
HUF	% who wait			11.2%
(1)	time they wait			7.57 min
t_s = 6.72	% utiliz.			11.2%
FWA	% who wait			20.0%
(3)	time they wait			5.00 min
t_s = 4.00	% utiliz.			20.0%
CONS	% who wait	5.0%	22.3%	78.9%
(9)	time they wait	2.38 min	4.34 min	24.93 min
t_s = 5.26	% utiliz.	26.3%	39.5%	78.9%

8/30/77, 0400   9 transactions, 0 lost calls

To evaluate "consolidation," compare "x" servers under CONS with any combination from IND, HUF, and FWA that add up to "x." t_s is the average time to service one call; it varies with weather conditions.

% who wait: percent of callers who are put of "hold" or receive a busy signal
time waiting: average time of wait, considering only those who have to wait
% utiliz: percent of servers time spent in providing service.

*With one server, % utilization equals probability of getting a busy signal

QUEUING MODEL APPLICATION FORM

LOCATION: IND
DATE: 9/1/77, 0000
WX: VFR

A.	Number of servers	M	1(1.0)
B.	Number of transactions	N	6
C.	Average serving time*	$E(t_s)$	1.15
D.	Observed waiting time (sec)		14.3
E.	Number of calls delayed	$E(w)$	1
F.	Average time of delay (sec)		74.0
G.	Number of calls lost		0
H.	Probability of waiting (E)	B	0.0192
I.	Utilization (05)	r	.0192
J.	Intensity (06)	M x r	.0192
K.	Average number waiting (A')	$E(w)$	.000
L.	Average number in queue (B')	$E(q)$	.020
M.	Average time* waiting (C')	$E(t_w)$	.023
N.	Average time* in queue (C'+02)	$E(t_q)$	1.17
O.	Average time* for those delayed (C'/10)	$E(t_d)$	1.17

QUEUING MODEL APPLICATION FORM

LOCATION: HUF
DATE: 9/1/77, 0000
WX: VFR

A.	Number of servers M	1(1.0)
B.	Number of transactions N	1
C.	Average serving time* $E(t_s)$	1.17
D.	Observed waiting time (sec)	13.0
E.	Number of calls delayed E(w)	1
F.	Average time of delay (sec)	13.0
G.	Number of calls lost	0
H.	Probability of waiting B (E)	0.0195
I.	Utilization r (05)	.0195
J.	Intensity M x r (06)	.0195
K.	Average number waiting E(w) (A')	.000
L.	Average number in queue E(q) (B')	.020
M.	Average time* waiting $E(t_w)$ (C')	.023
N.	Average time* in queue $E(t_q)$ (C'+02)	1.193
O.	Average time* for those $E(t_d)$ delayed (C'/10)	1.193

*Minutes

QUEUING MODEL APPLICATION FORM

LOCATION: FWA
DATE: 9/1/77, 0000
WX: VFR

A.	Number of servers M	1(.92)
B.	Number of transactions N	1
C.	Average serving time* $E(t_s)$	5.65
D.	Observed waiting time (sec)	5.0
E.	Number of calls delayed E(w)	0
F.	Average time of delay (sec)	0
G.	Number of calls lost	0
H.	Probability of waiting B (E)	0.0942
I.	Utilization r (05)	.0942
J.	Intensity M x r (06)	.0942
K.	Average number waiting E(w) (A')	.010
L.	Average number in queue E(q) (B')	.104
M.	Average time* waiting $E(t_w)$ (C')	.587
N.	Average time* in queue $E(t_q)$ (C'+02)	6.24
O.	Average time* for those $E(t_d)$ delayed (C'/10)	6.24

*Minutes

QUEUING MODEL APPLICATION FORM

LOCATION: Consolidated
DATE: 9/1/77, 0000

A.	Number of servers M	3(2.92)	2	1
B.	Number of transactions N	8		
C.	Average serving time* $E(t_s)$	1.715		
D.	Observed waiting time (sec)	10.5		
E.	Number of calls delayed E(w)	3		
F.	Average time of delay (sec)	32.7		
G.	Number of calls lost	0		
H.	Probability of waiting B (E)	0.0017	0.0235	0.2287
I.	Utilization r (05)	.076	.114	.229
J.	Intensity M x r (06)	.229	.229	.229
K.	Average number waiting E(w) (A')	0	.003	.068
L.	Average number in queue E(q) (B')	.229	.232	.296
M.	Average time* waiting $E(t_w)$ (C')	.001	.023	.508
N.	Average time* in queue $E(t_q)$ (C'+02)	1.72	1.738	2.223
O.	Average time* for those $E(t_d)$ delayed (C'/10)	.619	.968	2.223

*Minutes

DATA SUMMARY FOR 9/1/77, 0000

SERVERS		3	2	1*
IND	% who wait			1.9%
(6)	time they wait			1.17 min
$t_s = 1.15$	% utiliz.			1.9%
HUF	% who wait			2.0%
(1)	time they wait			1.19 min
$t_s = 1.17$	% utiliz.			2.0%
FWA	% who wait			9.4%
(1)	time they wait			6.2 min
$t_s = 5.65$	% utiliz.			9.4%
CONS	% who wait	0.2%	2.4%	22.9%
(8)	time they wait	0.62 min	0.97 min	2.22 min
$t_s = 1.72$	% utiliz.	7.6%	11.4%	22.9%

9/1/77, 0000   8 transactions, 0 lost calls

To evaluate "consolidation," compare "x" servers under CONS with any combination from IND, HUF, and FWA that add up to "x." t_s is the average time to service one call; it varies with weather conditions.

% who wait: percent of callers who are put of "hold" or receive a busy signal
time waiting: average time of wait, considering only those who have to wait
% utiliz: percent of servers time spent in providing service.

*With one server, % utilization equals probability of getting a busy signal